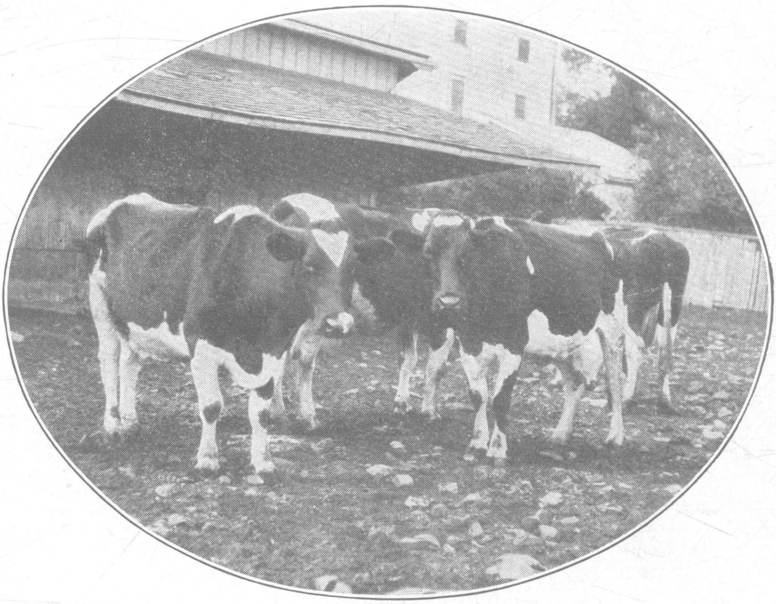
PROTEIN REQUIREMENT OF DAIRY COWS

OHIO
Agricultural Experiment Station

WOOSTER, OHIO, U. S. A., DECEMBER, 1925

BULLETIN 389



Sunshine and exercise but no pasture

The Bulletins of this Station are sent free to all residents of the State who request them. When a change of address is desired, both the old and the new address should be given. All correspondence should be addressed to EXPERIMENT STATION, Wooster, Ohio

This page intentionally blank.

CONTENTS

// BULLETIN

OF THE

Ohio Agricultural Experiment Station

NUMBER 389 DECEMBER, 1925

PROTEIN REQUIREMENT OF DAIRY COWS

A. E. PERKINS

Until recent years most of the available information regarding the protein requirement of dairy cows had been derived from experiments of short duration which failed to take account of a possible cumulative effect of the experimental feeding. Inadequately controlled herd experiments had furnished a major portion of the data. Statistics of doubtful value, and some very broad assumptions had also been called into use to supply needed information.

In an attempt to improve this condition, an investigation was started at the Ohio Agricultural Experiment Station in 1911 to study the effects of the long continued use of dairy rations departing markedly from the commonly accepted standards of protein content. Rations then considered quite extreme in either direction with respect to protein supply were adopted. After several years of continuous feeding of these rations, no marked difference could be detected either in production, composition of product, or condition of the animals. Wider extremes were then adopted and the experiment continued as before with the progeny of the original cows. These cows had been raised from weaning time on the same ration received by their dams and carried thru two or more lactation periods before changing the ration.

Metabolism experiments were conducted on individual cows from these groups, some phases of which have already been presented (24), (27), (31), (32). The data touching the minimum protein requirement of dairy cows afforded by these metabolism experiments and by the lactation periods of which the metabolism trials formed a part are the subject matter of the present discussion. The results of the earlier part of the entire project have not yet been published in full. One specification of our original plan called for a study of the effect of rations low in total protein but containing a high proportion of amids. It is felt that this specification has been fulfilled in the present study.

HISTORICAL

MAINTENANCE REQUIREMENT

The historical foundation of the various American feeding standards based on the work of Wolff, Lehmann, Kuhn, Kellner, Zunst, and others, has been repeatedly discussed by other writers (1) (19) and is well understood. Prior to the introduction of any of the American standards, the Wolff-Lehmann feeding standard had gained considerable popularity in this country. Haecker made the same protein prescription for the maintenance of milking cows as called for by the Wolff-Lehmann standard for the "resting ox"—namely, .7 pound digestible crude protein per 1,000 pounds live weight. However, the results in the three maintenance trials on which his maintenance standard apparently is based ranged from .5 to .72 pound daily, and live weight equilibrium was reached in at least one other case on as low as .29 pound protein daily (15). No nitrogen balances are reported in connection with this work.

Most of the other American workers who have suggested feeding standards for dairy cows, based on the same or similar units, have adopted Haecker's maintenance requirement without question. Prominent among these may be mentioned Woll and Humphrey, Savage, and Morrison.

Armsby (2), in reviewing the experimental evidence on which his protein requirement is based, cites two instances where nitrogen equilibrium was reached in the case of dry cows on .21 and .25 pound, respectively, crude protein daily per 1,000 pounds live weight. The lowest recorded results for steers are quoted as .27 pound crude protein, or .23 pound true protein. These exceptionally low figures are discarded by Armsby in making up his statement of the average requirement. The lowest value included was .43 pound crude protein or .38 pound true protein. In fixing his standard at .6 pound crude protein or .5 pound true protein per 1,000 live weight, Armsby states that a variation of as much as .2 pound in either direction may occur under varying conditions (2).

Eckles (11), in carefully conducted experiments on 7 cows, found that the average total energy usage for maintenance agreed well with Armsby's standard. He made no attempt to determine minimum protein requirement, but adopted Armsby's figures.

Hills (20), in comparing the results of his own extensive practical maintenance experiments with the requirements as set forth by Haecker, Armsby, and others, states that he was compelled to conclude that Haecker's figures are an overstatement of the requirements. His results indicated that Armsby's figures might also be too high, but he was reluctant to formally accept such a view in face of Armsby's record as a careful investigator and his extensive work in this line.

Buschmann and associates (8) reviewed much the same literature quoted by Armsby and in addition conducted extensive feeding experiments with milking cows. They concluded by recommending .45 pound true protein per 1,000 pounds live weight as sufficient for the maintenance of milking cows. In several individual experiments values somewhat less than this were observed after assuming that feed protein was 100 percent converted into milk protein.

PRODUCTION REQUIREMENT ABOVE MAINTENANCE

Haecker's protein requirement for milk production in its final form (14) was obtained by observing the consumption of feed protein and the production of milk protein by the cows in the University of Minnesota herd for eight winter-feeding periods. During some of these years rations considered relatively low in protein were fed. After deducting the liberal maintenance requirement, as stated above, the remaining feed protein was found to be approximately 1.38 times the observed protein content of the milk. Believing that his cows were more favorably circumstanced than the average, Haecker arbitrarily increased the observed factor 1.38 to 1.75, as the proper relation between feed protein and milk protein in estimating the amount of feed protein necessary to produce milk of different grades under average conditions.

Savage's (33) standard, derived in a similar manner from practical observations covering only the winter feeding period in the Cornell University herd, calls for approximately 35 percent more protein than prescribed in the Haecker standard; or, in brief, the requirement of feed protein according to this standard is slightly more than double the protein content of the milk according to Haecker's tables (15). Savage states in substance that his standard is intended for use in valuable purebred herds where high records are an asset, where the product commands a good price, and where protein-rich feeds cost little more than those lower in protein.

Morrison's (28) standard for milk production in addition to maintenance sets Haecker's figures as the lower limit and Savage's figures as the upper limit of digestible crude protein needed to produce milk of given grade. It is sometimes called the Modified Wolff-Lehmann Standard.

Before announcing his standard, Armsby (3) made a thoro review of the existing evidence but apparently found little exact information on which to base a standard.

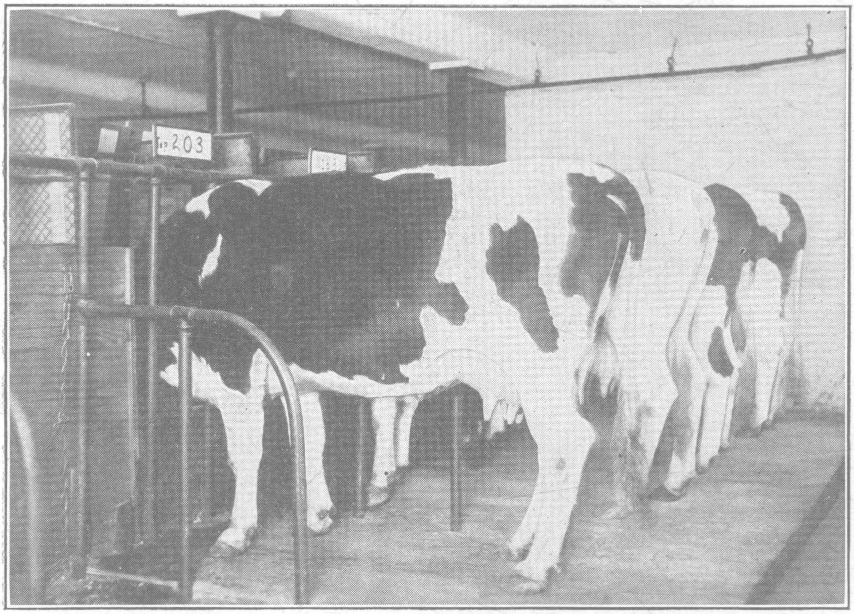
He closed the discussion by summarizing the herd experiments of Haecker (16) and of Woll and Humphrey (34) and concluded that, for commercial milk production in the United States, digestible food protein equivalent to 150 to 160 percent of the protein content of the milk produced, in addition to a proper maintenance allowance, is sufficient to sustain a normal rate of production. Accordingly his standard for milk production, as stated in Table 5 of the appendix to his textbook and elsewhere (4) (6), prescribes digestible true protein at the rate of approximately 160 percent of the protein content of the various grades of milk as shown by Haecker's tables (17). These tables give the amount of protein in milk corresponding to given percentages of fat as found by Haecker in his experiments. While apparently somewhat lower in protein than Haecker's standard, leaving the amid or non-protein nitrogen out of consideration may make the requirement equal to or greater than Haecker's when large amounts of material rich in Amids are fed.

Eckles (11) made no attempt to determine minimum protein requirement for milk production. His standard so far as protein is concerned being merely a statement of protein used by cows liberally supplied with protein. This is stated in terms of true protein, following Armsby's practice.

Likewise other feeding standards have been suggested but have failed to come to prominence. At most they differ only in minor details from those already discussed. Thus it will be seen that the leading American feeding standards for dairy cows rest almost entirely, so far as protein requirement for milk production is concerned, on three sets of winter herd feeding experiments—those of Haecker, Woll and Humphrey, and Savage, and that no serious attempt has been made in any of these experiments to determine minimum protein requirement.

Starting with a belief in the fundamental accuracy of these feeding standards, our own results at first seemed incredible. However, the extensive work of Hills and associates (22) begun about four years in advance of our own experiments, tho not published until 1922, corroborated our apparently phenomenal results obtained from long continued low protein feeding.

Buschmann and associates (8), in a recent discussion of an extensive series of carefully conducted short-time feeding experiments on milking cows, have challenged the conventional high protein requirement of the older standards. Apparently they have proved that an allowance of true protein only slightly exceeding the protein content of the milk in addition to a maintenance allowance, which is also less than prescribed in the older standards, is just as effective for producing milk as a ration of higher protein content. They maintain that, after the minimum of protein has been supplied, production follows the energy value of the ration or the specific properties of the feeds, rather than the protein content; and that beyond this point, with stationary energy content, production is independent of the protein supply.



Cows in "metabolism" stalls at beginning of experiment 1923-24

Fries, Braman, and Kriss have recently reported observations on two cows on metabolism experiment. They observed a slight nitrogen loss with one cow and a slight nitrogen retention with the other, on a ration containing an amount of digestible true protein equal to 1.03 times the protein content of the milk; or, an amount of digestible crude protein equal to 1.25 times the protein content of the milk, in addition to Armsby's prescription for maintenance.

Forbes and Swift have very recently studied the nitrogen, or protein, utilization of dairy cows during an extensive series of metabolism experiments. The cows in their experiments were receiving an abundance of protein, however, so the results throw little light on our present problem of actual protein requirement.

THE EXPERIMENT

The details regarding the rations, cows, and methods employed during the metabolism periods of these experiments have been presented in our earlier papers, (26) (27) (31) (32). They include a preliminary individual weighing, sacking, and sampling for analyses of all the feed used; separate collection and daily sampling of both solid and liquid excreta; careful weighing and sampling of the milk; daily weighing and exercise of the cows. Altho one sample in such work frequently is made to cover the entire experimental period, the sampling of all the products was conducted in such a way that from three to as many as six samples were prepared and analyzed, each representing a comparatively short period.

The cows were continued on the same rations used during the metabolism trials to the end of their respective lactation periods. The detailed work of feeding and sampling, however, naturally gave way to the regular barn routine. These cows were treated exactly as the remainder of the herd, except that during the pasture season they were confined to a dry-lot entirely devoid of vegetation while the main part of the herd was at pasture. The regular routine includes, feeding, milking, and watering twice daily, weighing the cows regularly, weighing and recording all feed supplied and milk produced and regular testing of the milk for butterfat content. More complete chemical analyses were also conducted at intervals on one-day composite samples of the milk from cows 146 and 154; and with one exception, as noted later, the usual proximate analyses were conducted on the feeds supplied.

THE RESULTS

Table 1 gives needed information regarding the cows used. Special attention is called to the nitrogen balances found in the last line of Table 1. In spite of rations which were very low in protein the cows were, with two exceptions, decidedly in positive nitrogen balance. The two cows in negative balance had recently been transferred from rations containing an abundance of protein and the nitrogen losses are thought to have been due to the readjustment to new conditions with respect to nitrogen metabolism. The figures given are the average for the 36 days of the metabolism experiment. If only the last 18 days are considered, the negative balances are greatly reduced, as shown in a former article (27).

There was one loss in live weight of 450 pounds and the average for all these cows was more than 300 pounds. Such losses occurred only at calving time and in early lactation, however, and were fully restored before the succeeding calving without change in ration.

Another feature worthy of special comment is the birth weights of the calves at the conclusion of the low protein feeding as here recorded. With the exception of cow 146, which, as noted in the table, aborted at the end of approximately 7 months, all the calves were vigorous, healthy individuals and of good weight; indeed, the birth-weights of these calves are among the highest recorded in the Ohio Experiment Station herd. Thirteen months later, while still on the same ration, cow 146 dropped a vigorous, normal calf weighing 110 pounds, thereby to a considerable degree allaying suspicion which might otherwise point to this ration as the cause of the abortion.

Table 2 shows the amount of the individual feeds supplied; and Table 3 shows their composition with respect to digestible crude protein and total digestible nutrients. These were computed according to average figures; also according to observed analyses in connection with the customary average digestion coefficients. Table 3 also gives the digestible true protein and net energy according to Armsby's figures (1) (6).

It is necessary to call attention to one irregularity in connection with this table: The protein content shown for the timothy hay of 1923-24 was that found for the hay used at the time of the metabolism experiment. This supply did not last thruout the remainder of the lactation periods. That used later was of better quality and presumably of higher protein content, but, unfortunately, its analysis was overlooked. The average figure of 3 percent for digestible crude protein was used for this hay in calculating the protein content of the rations affected. The total digestible nutrients of the timothy hay which was analyzed agree closely with the average figures and has been used for all without correction.

Table 4 gives the digestibility of each nutrient for the entire ration as calculated by the use of average digestion coefficients and actual analyses for each feed employed. It also shows the digestibility of each nutrient in the entire ration as observed in our metabolism experiments, and gives a comparison of the two. The outstanding feature is the much lower digestibilities observed than those calculated from average figures. This has been discussed more in detail in our previous papers (31) (32).

Table 5 gives the data regarding the production of milk, milk fat, and milk protein. All given values for the metabolism period were determined by direct analyses of samples secured at that time. The productions of milk and fat over the longer intervals were taken from the regular herd records. The protein in this latter case was calculated by the use of a table published by the writer (30) showing the relation between the fat and protein content of a large number of samples of milk. The ratio of protein to fat found in this study runs slightly higher than the ratio observed by Haecker and used by him and also by Armsby in formulating their respective feeding standards. In two instances where a comparison was available this calculated production of protein over the longer period agreed closely with the figures obtained from direct analyses made on one-day composite samples of milk at intervals during the lactation period. The proportion of protein to fat observed in the milk during the metabolism experiment in case of some of the cows was considerably higher than the calculated values derived by the use of either the writer's or Haecker's tables.

Table 6 gives the supply of total nutrients and of protein calculated in various ways.

Table 7 presents a comparison of the requirement of these cows, as figured by the Haecker standard from the live weight and production, and the nutrients actually supplied them, based on average figures for the composition and digestibility of the feeds supplied. The supply of protein figured in this way was deficient in amounts ranging from .27 to .57 pound daily during the metabolism experiments, and by as much as 204 pounds during one of the longer periods. If the actual analyses instead of average figures were used, the deficiencies would be greater, for the actual analyses were below the average with respect to protein. There was a considerable excess of total digestible nutrients in each case except one, that of cow 154 during the 5th, or 1922, lactation period, in which there was a slight deficit.

The use of our actual analyses instead of the average analyses, makes comparatively little difference in the statement of total digestible nutrients supplied. The result in case of cow 154 for 1922, however, is higher under this system.

The use of observed instead of average digestibilities would make a decided reduction in the apparent supply of both protein and total digestible nutrients.

Table 8 shows the relation of the same data to Armsby's standard. The amounts of true protein and net energy were calculated from Armsby's average figures. The deficiencies in true protein shown here are greater than corresponding deficiencies of crude protein according to the Haecker standard shown in Table 7. This is doubtless due to the fact that large amounts of dried beet pulp, silage, and cane molasses were used. These feeds altho carrying considerable quantities of crude protein, contained according to Armsby's figures only small amounts of true protein. The excesses of net energy were likewise more marked than the excesses of total digestible nutrients according to the Haecker standard. It has been observed by other investigators that Armsby's standard is inclined to be too low in its energy requirement for production (12) (20). This would favor the apparent excess as shown. Here again, if the actual analyses and digestibilities were employed instead of average values, the deficiencies of protein would be much greater and the excesses of energy somewhat less.

Table 9, line 1, shows in detail the supply of digestible crude protein for each cow, according to average figures. In line 2 the actual analyses, with the one exception noted on page 11, have been used in connection with the usual average digestion coefficients.

In line 3 the ratio between average and observed digestibility of protein for the entire ration has been applied to the values of line 2.

Line 4 shows the production of protein determined as described on page 373. The values in lines 5, 6, and 7, were derived by deducting the amount of protein produced as shown in line 4 from the total supply of digestible protein as shown in lines 1, 2, and 3, respectively. They represent the total supply of digestible crude protein available for all other purposes, after deducting from the total supply the amount actually produced in the milk, instead of 175 percent of that amount as called for in Haecker's standard.

Line 8 shows the requirement for maintenance alone as set forth in Haecker's standard. The residue of digestible protein, above that actually produced in the milk, was slightly in excess of this requirement if the average values of lines 1 and 5 are accepted. But the use of the observed values, as given in lines 2 and 6 and 3 and 7 makes the supply in most cases considerably less than this commonly used maintenance standard.

In line 9 of Table 9 is shown the amount of feed protein supplied for each unit of milk protein produced in these experiments, after deducting the Haecker maintenance requirement, and using the average figures of line 1 in computing the protein supply. The supply remaining on this basis was in each case, except one, in excess of the milk protein, tho far below the ratio of 1.38 to 1 observed by Haecker.

In line 10 the same computation is made, using the actual rather than average analyses of the feeds. In each case, except one, on this basis, the supply of protein in the feed was actually less than that produced in the milk. Since no ultimate source of protein supply for either maintenance or the production of protein in milk other than the crude protein of food is known, and the actual digestibility of the food protein in all our experiments was less than the average figures, it follows that the maintenance requirement of these cows, whose live weight record and general condition indicate that they were fully maintained, must have been considerably less than called for by the Haecker standard.

Table 10 shows the relation of the protein supply and protein production to the Armsby standard. Line 1 shows the amount of true protein supplied according to Armsby's average figures. The values shown in line 2 were obtained by applying the ratio between true and crude protein, as shown in Armsby's tables, to our analyses. The values of line 3 were obtained by applying to the corresponding values of line 2 the factors given in Table 4. These factors express the relation between the observed and the average calculated digestibility of protein in these rations.

Lines 5, 6, and 7 show the excess of true protein remaining above the protein actually secreted in the milk according to the three systems just described. In every case these values are much less than Armsby's maintenance requirement of true protein as shown in line 8, proving that either Armsby's maintenance requirement is too high or that the rather liberal supply of amids present, as shown in Table 8, must have been largely drawn upon for either the production of milk protein or for maintenance or both. Certainly, if much more protein than that actually contained in the milk is necessary for milk production, as Armsby's standard, as well as all the other standards, would lead us to believe, then the maintenance of these cows with respect to protein must have been entirely accomplished by the amids. The values of lines 9 and 10, Table 10, were obtained by deducting from the total available supply of true protein the amount required for maintenance by Armsby's standard. These values show the amount of true protein remaining for each pound of milk protein produced. The values will be seen to range from .45 to .77 pound. The distinction between true protein and amids in this case, at least, fades into insignificance. Moreover, the proportion of amids which occurred in these rations was higher than would be likely to occur in practical dairy rations, a consideration which would minimize the necessity of such a distinction between crude and true protein in practice. Armsby (6) practically recognized this status of the problem in reviewing older work, but somehow failed to give it expression in his feeding standard. Since average digestion coefficients were used in developing all the standards, we have not included our observed lower digestibilities in this comparison nor in the corresponding comparison of Table 9.

It is a far cry from the 45 to 77 percent of the milk protein represented by the true protein of the feed above maintenance of these experiments to the 150 to 160 percent prescribed in Armsby's standard; and yet, considering the monotonous and arbitrary character of the rations, a rather liberal production was maintained. We have no evidence whatever that the cows suffered in any way from a lack of protein, even tho cow 154 was confined to a ration of this character for two full successive lactation periods. There is nothing to indicate then that our cows were operating on a minimum or deficient supply of protein even at the low level of protein intake to which they were confined.

THE PROTEIN MINIMUM

Hills and associates (22) seem to have reached or slightly exceded the real minimum with respect to protein when they fed rations containing approximately 1 pound digestible crude protein per day per 1,000 pounds live weight to milking cows continuously over a period of several years. Reasonably good production was maintained and no abnormality noted with respect to reproductive ability tho the cows became visibly thin in flesh and the live weight declined slightly from year to year when normally a gain should have been expected. This work is defective, however, in that the cows received a limited amount of pasture in summer, the amount and influence of which can in no way be determined.

In Table 11 the results of this phase of the Vermont experiments are figured in somewhat different form than that in which they are presented in the original article. The headings and footnotes in the table are believed to offer adequate explanation of the various items. The reader is referred to the original article (22) for a further detailed explanation.

According to Hills and associates, from the standpoint of production, there was little choice between this and the rations higher in protein. In the last column at the right of this table it is seen that these cows were practically maintained during the 7 months winter periods when the total daily supply of digestible crude protein was only .445 pound above the amount of protein actually produced in the milk. As the average weight of these cows was 836 pounds, this was equivalent to .532 pound per 1,000 pounds live weight.

This agrees well with Buschmann's recommendation (9) of .45 pound true protein per 1,000 pounds live weight, when the relation between true and crude protein is that which occurs in the average ration. By reference to Table 9 and by using the values of lines 2 and 6, it will be seen that our cows were not on quite so low a level of protein usage as those in the Vermont experiments. According to the values of line 7, derived by the use of the observed digestibility of the ration, the cows were, in proportion to their live weight, being maintained on a smaller amount of protein. This is hardly probable, however, since the Vermont ration had a slightly wider nutritive ratio than the ration used in our experiment. Moreover, average digestion coefficients were doubtless employed in calculating the Vermont results; hence the values of line 6 would be likely to yield a closer comparison.

The values seen in column 6 of Table 11 remind one of the remarkably low maintenance figures quoted by Armsby (2) as emanating from Danish investigators. Altho these Vermont figures represent several full lactation periods, it must be borne in mind that the cows received a small but unknown amount of food from pasture during the summer. On this account the values of column 11 are probably nearer the minimum of protein which can be said to provide maintenance for the milking cow.

In this discussion the crude protein requirement for milk production is considered to be exactly equal to the protein content of the milk. Without radical revision of the fundamental conceptions of nutrition, it can scarcely be conceived to be less than this. All of the recognized older standards prescribed from 50 percent to more than 100 percent as the necessary or desirable margin of food protein, in excess of milk protein.

Hart and Humphrey (18) emphasize the use of reserve supplies of protein and continued negative nitrogen balances which are said to have taken place in some of their experiments even when the cows were apparently maintaining their live weight. The rapidity with which cows 163 and 203 in our experiment reduced the rather high nitrogen losses of the first half of the metabolism periods would not indicate any such extensive losses of protein under our conditions. The observed losses would doubtless have been greater and longer continued if the marked change in ration with these cows had been made earlier in the lactation period.

FEEDING REQUIREMENTS AND FEEDING STANDARDS

While, with so few results, we shall not attempt to propound a standard, we do feel justified, however, in pointing out certain inconsistencies with respect to the derivation and use of the common standards with reference to protein content, and in pointing out the relationship of our results to a recently announced European standard not yet familiar in this country.

There has been little or no attempt on the part of the American standard makers to ascertain the protein minimum. Indeed, it seems to have been studiously avoided. Haecker's standard, which is one of the lowest with respect to protein, was derived as the result of several winter herd feeding experiments. Haecker's only evidence that any of his rations at any time were deficient or even at the minimum with respect to protein content seems to have been that one Judge was able to select the animals fed the low protein ration from those on the high protein ration when they were brought into the judging-ring by pairs. This is said to have been accomplished chiefly by noting the texture of the skin and the "spareness" of the low-protein group, particularly those individuals which had been on the low-protein ration for more than one season. Other judges were unable consistently to detect any considerable difference between the two groups.

Hills and associates (22) have repeated this phase of Haecker's work on cows which were receiving much more radical treatment with respect both to protein supply and to duration of the experiment, than anything described in Haecker's experiments. The animals were examined by a larger number of judges and under the fairest of conditions, and the examinations were repeated on numerous occasions. Within the limits discussed by Haecker, the data fail entirely to confirm his conclusions regarding a definite relationship between proportion of protein in the ration, and "feel of skin", "spareness", or any one of the many points on which judgment was attempted. Haecker also mentions an instance where increasing the proportion of protein or lowering the nutritive ratio of the ration fed his herd brought about an increase of weight while maintaining production at the former level. This is likewise used as evidence favoring the higher protein feeding. Hills and associates, using winter rations of lower protein content than any reported by Haecker, satisfactorily maintained the live weight of their cows and liberal production at the same time over periods of several years. The writer accomplished like results even with continuous yearround feeding of such low protein rations for several successive lactation periods.[1] The eight winter feeding periods on which Haecker's protein requirement for milk production is based include periods of liberal, as well as periods of low, protein feeding.

Haecker can scarcely be deemed to have determined the minimum protein requirement for either maintenance or production and certainly his standard with its great amount of added tolerance, as previously explained, does not represent any such minimum. The same criticisms apply to Armsby's protein requirement for milk production in addition to maintenance (4) for it is based on Haecker's work and on other work of like character. There is no apparent attempt to state a minimum requirement. The latter is mentioned in Armsby's preliminary discussion of the problem (3), but does not appear in the standard as announced (4) (7). Other standards copied in whole or in part after one or the other of these are like unto them in this respect.

Buschmann and associates (8) have apparently shown in their short-time experiments that feed protein equal in amount to the milk protein produced is adequate to meet the production requirement. In their standard as announced an allowance of 25 percent above this amount is included. The writer would interpret his own results and those of Hills and associates to mean that this standard is ample over long periods under the conditions prevailing in the experiments cited.

USE AND ABUSE OF FEEDING STANDARDS

Feeding standards tho very useful as practical guides to feeding must not be taken too seriously. Armsby (5) has very aptly pointed out the limitations of all feeding standards. He laments the craving of the human mind for a "recipe" and particularly the use of feeding standards in this way. Henry and Morrison (19) emphasize the same idea. However, many of our leading teachers and publicists do not seem to realize the true significance of this situation, and are liable to be led blindly into grievous error by following too closely the precise dictum of some feeding standard.

None of our present feeding standards can rightly be interpreted as a minimum standard so far as protein is concerned. Their use in this way may be compared to the use of a yardstick or bushel which instead of being the true standard measure (in this case not fully established) is, say 50 percent to 100 percent, oversize to allow for a possible shrinkage or impurity of the goods to be

[1] A. E. Perkins, Ohio Agr. Exp. Sta. Unpublished results.

measured. For the actual purpose for which they were intended such measures may be useful and answer every requirement. But if, inadvertently, such measures be used for other purposes where the real standard measure is desired the resulting measurements would be worse than useless, for they would be badly misleading. For similar reasons, it is not expedient to use any of our present feeding standards as actual measures of the minimum requirement, especially as regards protein.

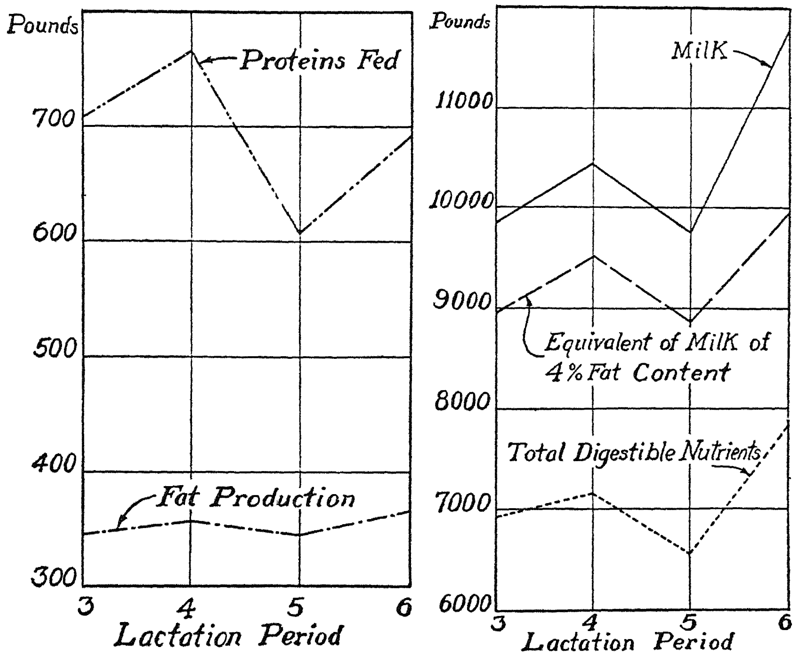
PROTEIN OR PALATABILITY?

It has quite generally been taught in the past that regardless of the minimum of protein which might suffice for the needs of the milking cow, a liberal surplus is necessary, or at least highly desirable from the standpoint of liberal and efficient production. The extra protein has been looked upon as a kind of stimulant to increased production. Experiments of Hills and associates, just quoted in part, and those of Buschmann and associates of Riga, Latvia over shorter periods would seem to place a large question mark after much of such teaching. Some of the data already presented in this article, combined with earlier data from the same animals, afford a pertinent comparison touching this point

The feed and production records of cows 146 and 154 for four successive lactation periods are presented in Table 12. During this time they received rations varying widely as to protein content, altho in other essential respects they were handled and cared for exactly alike.

The milk record and record of digestible nutrients supplied have been computed to the average daily basis, and thence to a hypothetical period of 366 days. The interrelation of these values is more easily apparent when presented in graphic form, as in Graphs 1, 2, 3, and 4.

The similarity of the curves representing total digestible nutrients supplied and milk produced is apparent. The curves of digestible crude protein supply show much less relationship. In case of cow 146, Graphs 3 and 4, between the fourth and fifth periods, a drop of nearly 400 pounds, or 31.5 percent, in amount of protein is accompanied by an increase of some 778 pounds, or 7¼ percent, of milk produced. At the same time there is an increase of some 1,620 pounds, 25½ percent, in the amount of total digestible nutrients supplied. The still further cut in protein supply in the sixth period is again accompanied by an increase in milk production, but the milk was of lower fat content as reflected in the curve showing production of fat during the same periods. Graphs 1 and 2 show a strong similarity between the curves representing the supplies of protein, total digestible nutrients and the milk production for cow 154 during the third and fourth periods. Again, they show similarity within the fifth and sixth periods. At these times the nutritive ratio remained constant. The similarity in the curves is interrupted between periods four and five, however, corresponding to the change in ration.



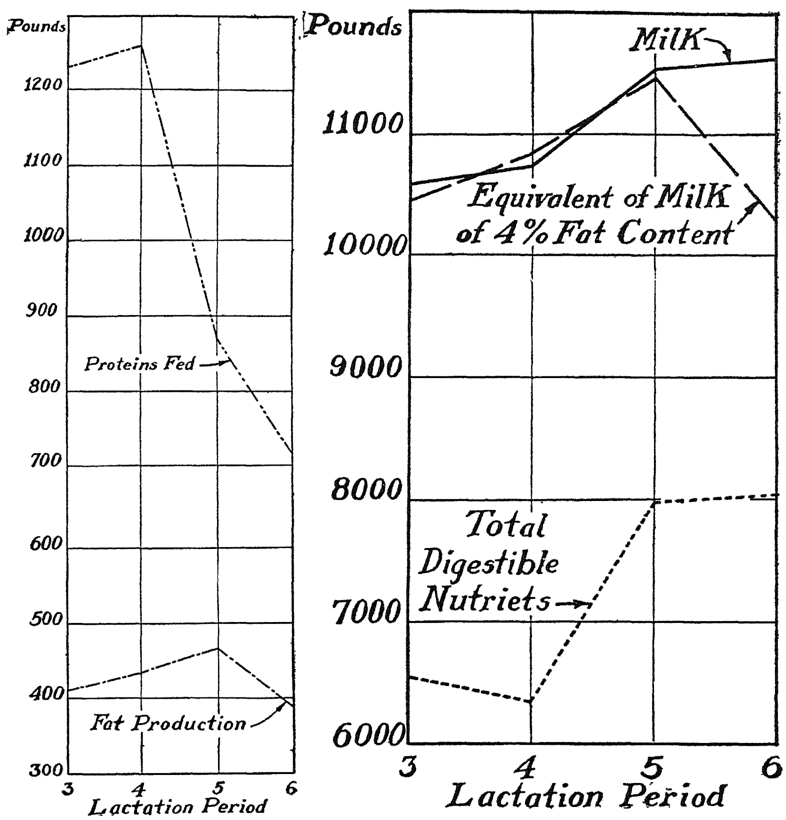
Graphs 1 and 2.—Curves showing relation between feed supply and production at different levels of protein feeding—Cow 154

A very marked decline in protein supply is accompanied by only a slight decline in the other items in keeping with a corresponding decline in total digestible nutrients.

There is a marked indication in these data from cows 146 and 154 that the very low protein ration used in 1923-24 was responsible for the lowering which occurred in the fat content of the milk produced. This point is dismissed for the present, however, to be studied in detail in a later publication in connection with other data of like nature.

In Table 13 and Graphs 5 and 6 we have briefly summarized our older data to show their bearing on this important question of the effect of protein content of the ration on the economy of production.

The detailed information regarding feeds supplied, live weights, and breeding records of cows, milk and fat production, analyses of feeds and product, together with further discussion, will appear in a later publication. In this bulletin the average analyses of the feeds have been used. The feed record in most cases extended over the full 365-day period.

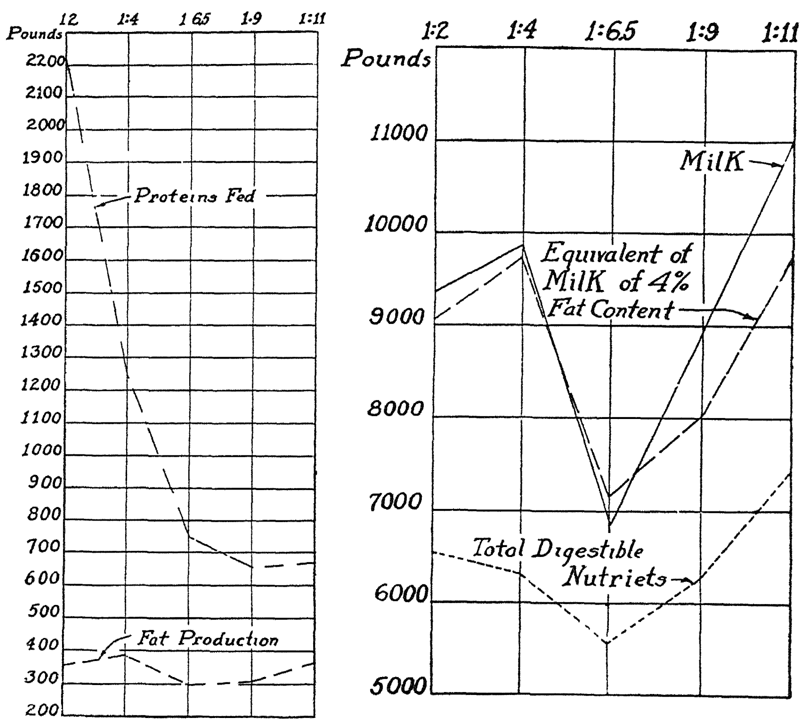


Graphs 3 and 4.—Curves showing relation between feed supply and production at different levels of protein feeding—Cow 146

The milk production was determined by weighing and recording each milking. Each milking was also sampled and the fat percentage determined by weekly tests by the Babcock volumetric method on these composite samples.

In calculating the milk and fat production to a 365-day basis the stripper period was omitted. If the period continued for some time more than 365 days the first 365 days were taken; if less than 365 days, the final entire month's production was compared with that of the preceding month. If it was more than 50 percent of the preceding month, it was included in the period on which the average daily production was calculated; if less than 50 percent, it was omitted altogether in calculating the average daily production. The production of any fractional part of a calendar month occurring at the end of the lactation period was nearly always so small that it was omitted by following this rule. The average daily production multiplied by 365 gives the production on the 365-day basis as shown in column 3 of these tables.

The average percent fat was determined by dividing the total fat production by the total milk production.



Graphs 5 and 6.—Composite curves showing relation between feed supply and production at different levels of protein feed

The conversion of all these production figures to their equivalent in 4 percent milk was accomplished by means of a table prepared by the writer and based on previously published data (30) (31).

Very little difference, indeed, exists in the economy of production between the different groups of rations in spite of the tremendous differences in protein content. The individual differences within any of the larger groups are much greater than the differences between the group averages, showing that protein content in itself is not such a very important factor in determing economy of production per unit of feed supplied.

Almost the only evidence afforded by these data tending to indicate that high-protein content of a ration favors liberal production, is found in the high return, per pound of digestible nutrients supplied, made by the cows on the 1:4 ration. Even here we must not make the same mistake which has been made repeatedly by the older investigators of ascribing unreservedly to protein an influence which may equally well be due to other causes, such as greater proportion of legume hay and grains of higher vitamin, mineral or other content.

In spite of the effort to make equal grouping, these very favorable results with the 1:4 ration may have been due largely to individuality of one or more of the cows. At all events the results as a whole show little relationship between the proportion of protein in the ration and the economy of production.

The wide and narrow rations in the early part of these experiments contained exactly the same ingredients. Any feed used in one ration was used in all, only the proportion varied. We aimed by this means to avoid being misled by the effect of any specific properties of the feeds. The proportion of the various feeds making up the rations was calculated in advance. Each cow was allowed as much of her particular ration as she would consume regularly without waste, always keeping the various ingredients of the ration in the fixed proportion. Timothy hay was an ingredient of nearly all these earlier rations, being used in connection with a legume hay as an aid in securing the prescribed protein balance. Usually it was the least desired ingredient of the ration, and, therefore, the factor which constantly had a retarding effect on total food consumption.

During the fifth lactation period of cows 146 and 154 the same condition prevailed. Cow 154 showed a falling off both in total digestible nutrients consumed and in milk produced on the new ration, nutritive ratio 1:11, used during this period. During the sixth lactation period neither cow received any other hay than timothy; but cane molasses diluted with approximately its own volume of water was sprinkled over this hay causing it to be much more readily consumed, and with it more of the entire ration. This we consider the chief cause of the greater food consumption and consequent greater milk production of this period. This hypothesis, however, does not account for the marked increase in both feed consumption, and production of cow 146 during the fifth lactation period.

A person has only to recall what an overwhelming influence the palatability of his food plays in his own peace of mind, health, and efficiency, and to remember that the dairy cow is a highly developed nervous and temperamental animal with pronounced likes and dislikes, to understand that the foregoing is a reasonable explanation of the performance of these cows.

It seems, then, that palatability favoring a heavy feed consumption, and probably other factors also, may be of greater significance than protein content in determining the productive returns from a given ration. This relation would not necessarily hold to the same extent where the unpalatability of one feed was not allowed to influence the remainder of the feed supply. Still it may very probably be a potent factor in the productiveness of a ration. It is our belief that much of the difference in productiveness between rations, which in the past has popularly been attributed to variations in protein content, may with equally good logic be attributed to differences in total food consumed due to palatability, or to differences in palatability per se. Palatability and liberal protein content of normally cured hays seem to go hand in hand, a condition favoring mistaken judgment on the point in question. Similarly, in discussing his own results, Buschmann (10) has reviewed and criticised in detail several of the older European experiments which have been used as the basis for most of our feeding standards. He quotes portions of these experiments showing that the differences in production on which the recommendations for high-protein feeding are based are, for the most part, insignificant, and do not furnish a sufficient basis for such recommendations. Buschmann finds that the experiments were carried out on too small a number of animals and were not sufficiently well controlled to be satisfactory according to modern standards. He finds that in many cases the results attributed to protein may have been due to increased energy content, or specific effects of the feeds. In some cases, Buschmann would interpret the results in a way just opposite to that in which they were previously interpreted.

IMPORTANCE OF VARIETY IN RATIONS

One point, which must not be overlooked in the interpretation of our result, is that our cows had at all times a good variety of feeds in their ration. This condition is in decided contrast to that prevailing in many of the experiments on which our present feeding standards are based. One or at most two feeds seem to have been the rule in these experiments. For example, the ration on which Haecker secured live weight equilibrium on .29 pound digestible protein daily, (15) the results of which were discarded in making up his standard on the ground that the cows did not seem in proper physical tone, consisted entirely of fodder corn. The basal ration in many of the time-honored experiments whose results have supplied the foundation of our feeding standards consisted solely of "meadow hay." In the light of more recent experiments regarding the biological value of various proteins and the supplemental effect of one on another (24) (25) (29) and other work by the same authors, it is easy to understand how such a ration consisting of protein from only one source might prove unsatisfactory in the way indicated while another ration containing no greater total quantity of protein but derived from different sources could be entirely satisfactory. Investigations in this field have not progressed far and to date are limited largely to maintenance and growth experiments with the albino rat. They are merely suggestive so far as their application to the problem of present discussion is concerned. A beginning has been made, however, of similar studies with dairy cows—Hart (18), Hayden[2], and Larsen (23). The results so far reported suggest the importance of securing protein from various sources in any dairy ration.

It is the opinion of the writer, based on an incomplete survey of the literature, that most of the apparent justification for a nutritive distinction between crude protein and true protein has arisen under just such conditions; and that the importance of this distinction is reduced as we increase the variety of feeds in the ration. We can readily understand how the long continued use of rations similar to those fed in this experiment, but containing less of a variety, may have led to less desirable results. However, experimental data on which to base any definite conclusion in this regard

[2]C. C. Hayden, Ohio Agr. Exp. Sta. Unpublished results.

are lacking. The influence of minerals and vitamins, which has held such a prominent part in the literature of feeding investigations during the past decade, was either unknown or regarded as unimportant at the time the basal work underlying our present feeding standards was conducted. While all the details regarding the influences of these factors are not yet well understood, it is not at all improbable that they exerted an unrecognized influence on some of these experiments and that this influence very naturally was credited to protein.

PRACTICAL SIGNIFICANCE

The practical economic significance of these results if confirmed by later investigation is almost beyond computation. It has been difficult, if not impossible, for dairy farmers in large sections of the country to grow rations for their cows containing as large a proportion of protein as seems necessary according to the feeding standards now in use. It has been quite generally taught that, unless such protein requirement be met, the use of the home-grown ration involved a decided waste. Accordingly, it has been necessary to buy from oil-crushing mills their high-protein by-products in order to meet the protein demand of cows as interpreted by present feeding standards. Such feeds are nearly always more expensive than locally grown feeds of the same or higher energy content.

If it should be confirmed that less protein is absolutely necessary than formerly supposed and that production is more directly dependent on the consumption of total digestible nutrients or net energy than on the consumption of large amounts of protein, farmers will be more nearly independent of expensive purchased dairy feed. The dairyman who can grow roughage (legume hay and silage) of the highest quality and palatability and who feeds liberally of these and of a mixture of locally-grown grains and wheat bran, if he has been following the older standards, should be able to reduce very materially the customary amount of purchased protein concentrates without marked reduction in the amount of production. Indeed, our results seem to indicate that even the non-leguminous roughages, if palatable and accompanied by a liberal feeding of the common grains, are capable of yielding good results. Altho the protein content of feeds is an important consideration, especially in the case of hays where protein content and palatability seem to run nearly parallel, our results show that perhaps too much attention has been focused on protein and not sufficient attention on palatability, liberal feeding and, possibly, other factors.

CONCLUSIONS

1. These cxperiments, to the best of our knowledge, are the first to be reported covering the entire lactation period on fully controlled low protein feeding.

2. The cows produced liberally; appeared normal with respect to reproduction; and maintained their live weight from year to year.

3. The amount of digestible crude protein supplied was much less than that prescribed by the Haecker Standard for corresponding live weight and production, while the amount of total digestible nutrients was considerably in excess of that demanded.

4. The deficiencies of "true protein" and the excesses of "net energy" supplied in comparison with the Armsby Standard were much greater than the corresponding discrepancies measured by the Haecker Standard. This was due in part, it is thought, to the unusually low percentage of true protein and the unusually high percentage of amids contained in the rations used.

5. When the protein actually produced in the milk of the cows was deducted from the total supply, the difference was less than prescribed by the respective standards for the maintenance of dry barren cows of like weight.

6. When the maintenance requirement of protein called for by the respective standards was deducted from the total supply the remainder was much less than the amount actually produced in the milk.

7. These milking and pregnant cows were fully maintained on smaller amounts of protein than prescribed by the respective standards for dry barren cows.

8. The distinction between "true protein" and "crude protein" seems to have been without great significance under the conditions prevailing in this experiment.

9. In the case of cows 146 and 154, under widely different conditions of protein supply, the milk production seemed to follow the supply of total digestible nutrients rather than that of protein.

10. Our results harmonize nicely with the extensive results reported by Hills and associates (22).

11. Our results also support the contention of Buschmann and associates (8) that the older standards call for unnecessarily high amounts of protein; that the actual maintenance requirement is less than prescribed in these standards; that above this maintenance requirement an amount of digestible protein only slightly greater

than the protein content of the milk appears to be adequate; and that beyond this point, production seems to follow "total digestible nutrients" or "net energy" or "starch value" of the ration, rather than protein content.

12. The results of 51 full lactation periods on fully controlled feeding arranged by groups according to protein content of the rations, which covered a range of 8⅓ percent to 33⅓ percent, failed to show any marked or consistent effect of high protein content in increasing the productive efficiency of the ration.

13. Variety in the rations is thought to have had an important bearing on the favorable results secured with rations so low in protein.

14. These results, if confirmed by later investigation, should be of great economic significance.

LITERATURE CITED

(1) Armsby, H. P., The nutrition of farm animals, The MacMillan Co., New York City, 1917. (2) p. 326. (3) p. 501. (4) p. 511 and 714. (5) p. 691.

(6) Armsby, H. P., The nutritive value of the non-protein of feeding stuffs, Bureau of Animal Industry, U. S. Dept. Agr. Bul. 139, 1911.

(7) Armsby, H. P. and F. S. Putney, Computation of dairy rations, Penn. Agr. Exp. Sta., Bul. 143.

(8) Buschmann, A. and associates, Untersuchungen über den Eiweissreicher bedarf der Milchkuh und den emfluss Eiweissreicher und eiweissarmer Futterung auf die Menge und Zuasmmensetzung der Milch. Landw. Vers., Stat. Vol. CI, Heft I-IV, 1923. (9) p. 197 and elsewhere. (10) p. 206-215.

(11) Eckles, C. H., Nutrients required for milk production, Univ. Missouri Agr. Exp. Sta. Res. Bul. 7, 1913.

(12) Ellet, W. B., C. W. Holdaway, and W. G. Harris, Feeding standards for milk production, Virginia Agr. Exp. Sta. Tech. Bul. 23, 1921.

(13) Fries, J. A., W. W. Braman, and M. Kriss, On the protein requirement of milk production, Jour. Dairy Sci. 7, p. 11, 1924.

(14) Forbes, E. B. and R. W. Swift, The efficiency of utilization of protein in milk production as indicated by nitrogen balance experiments, Jour. Dairy Sci. 8, p. 15, 1925.

(15) Haecker, T. L., Investigations in milk production. 1, The food of maintenance, Univ. Minnesota, Agr. Exp. Sta. Bul. 79, 1903. (16) and (17) Bul. 140, 1914.

(18) Hart, E. B., and G. C. Humphrey, The relation of the quality of protein to milk production IV, Jour. of Biol. Chem., 35, 367, 1918.

(19) Henry, W. A. and F. B. Morrison, Feeds and feeding, The Henry—Morrison Company, Madison, Wisconsin.

(20) Hills, J. L., The maintenance requirement of dairy cattle, Univ. Vermont Agr. Exp. Sta. Bul. 226, 1922. (21) The same p. 68-101.

(22) Hills, J. L. and others, The protein requirements of dairy cows, Univ. Vermont Agr. Exp. Sta. Bul. 225, 1922.

(23) Larsen C. and associates, Relative values of feed protein for dairy cows, So. Dakota Agr. Exp. Sta. Bul. 188.

(24) McCollum, E. V., N. Simonds, and W. Pitz, The nature of the dietary deficiencies of the oat kernel, Jour. Biol. Chem. 29, 342, 1917.

(25) Mitchell, H. H., Supplementary relations among proteins, Jour. Biol. Chem. 58, No. 3, page 923, 1924.

(26) Monroe, C. F., The metabolism of calcium, magnesium, phosphorus, and sulphur in dairy cows fed high and low protein rations, Jour. Dairy Sci. VII, No. 1, 1924.

(27) Monroe, C. F., and A. E. Perkins, The mineral metabolism of dairy cows as affected by distilled water and previous feeding, Jour. Dairy Sci. VIII, No. 4, July, 1925.

(28) Morrison, F. B., Morrison (or modified Wolff-Lehman) feeding standards for farm animals. Feeds and Feeding; The Henry-Morrison Co. Madison, Wis., 18th ed., page 746, 1923.

(29) Osborn, T. B., L. B. Mendell, Nutritive factors in plant tissues, Jour. Biol. Chem. 34, page 521, 1918; also Jour. Biol. Chem., XX 351, 1915; XXVI 1, 1916; and XXXI, 1917.

(30) Perkins, A. E., Variations in the composition of skimmilk. Ohio Agr. Exp. Sta. Monthly Bul. I, No. 10, October, 1916.

(31) Perkins, A. E., and C. F. Monroe, The effect of high and low protein content on the digestibility and metabolism of dairy rations. Ohio Agr. Exp. Sta. Bul. 376, 1924.

(32) Perkins, A. E. and C. F. Monroe, The apparent digestibility of low protein rations by dairy cows, Jour. Dairy Sci. VIII, No. 5.

(33) Savage, E. S., A study of feeding standards for milk production, Cornell Univ. Agr. Exp. Sta. Bul. 323, 1912.

(34) Woll, F. W., and G. C. Humphrey, Studies of the protein requirement of dairy cows, Univ. Wisconsin Agr. Exp. Sta. Res. Bul. 13, 1910.

TABLE 1.—Data Regarding Cows Used in the Metabolism Experiments

Cow number	146	154 1922	154 1923—4	163	203
Breed	H. F. gr.	H. F.	H. F.	H. F.	H. F.
Previous feeding	Dry feed	Dry feed	Dry feed	Herd	Herd
Lactation period, number	6	5	6	5	2
Age, years	8.5	7	8.5	7.5	6
Date last calving	7—8—'23	1—21—'22	3—12—'23	8—7—'23	1—23—'23
Day of lactation at beginning of experiment	147th	182d	263d	118th	343d
Total length this lactation period, days	268	363	366	340	509
Live weight record					
Weight before calving, lb	1,538	1,575	1,561	1,423	1,339
Beginning lactation period, lb	1,343	1,281	1,325	1,259	1,012
Beginning metabolism experiment, lb	1,203	1,135	1,301	1,304	1,126
Close metabolism experiment, lb	1,206	1,145	1,352	1,278	1,130
Close of lactation, lb	1,433	1,438	1,461	1,402	1,240
Before next calving, lb	1,430*	1,561	1,595	1,515	1,365
Birth weight of calf, lb	....	122	109	95	95
Av. daily nitrogen bal. during met. exp. grams	+6.4	+14.5	+9.6	—3.8	—1.5

*Aborted 7-month calf.

TABLE 2.—Amount of Feed Supplied

Cow	Days	Period	Wheat bran	Ground corn	Ground oats	Corn silage	Beet pulp	Timothy hay	Cane molasses	Clover hay	Linseed oilmeal	Soybean oilmeal
154	363	5	691	2,219	63	4,452	2,337	2,215	....	1,477	....	....
154	366	6	1,141	2,264	1,123	1,818	2,849	3,748	616	....	....	....
146	268	6	846	1,717	819	....	2,540	2,675	464	55	5.5	5.5
163	183	6	583	1,166	583	....	1,745	1,840	330	....	....	....
Average daily feed during metabolism experiment												
154	1922		2.25	6.75	....	....	10.95	6.75	....	4.5	....	....
154	1923—24		3.25	6.50	3.25	....	9.80	10 50	1.30	....	....	......
146	1923—24		3.25	6.50	3.25	......	9.80	10.50	1.30	....	....	......
163	1923—24		3.25	6.50	3.25	....	9.80	10.50	1.30	....	....	.....
203	1923—24		3.17	6.50	3.17	......	9.59	10.25	1.27	....	....	....

TABLE 3.—Composition of Feeds Used*

	Wheat bran	Ground corn	Ground oats	Beet pulp	Corn silage	Timothy hay	Clover hay	Cane molasses	Linseed oilmeal	Soybean oilmeal
Digestible crude protein, H. and M. tables	12.5	7.5	9.7	4.6	1.1	3.0	8.1	1.0	30.2	39.7
Total digestible nutrients, H. and M. tables	60.9	85.7	70.4	71.6	17.7	48.5	50.9	59.2	77.9	84.5
Digestible crude protein. Actual analyses, average digestion coefficients, 1922	10.96	6.70	...	4.45	1.14	3.11	7.16	...	...	...
Digestible crude protein. Actual analyses, average digestion coefficients, 1923—24	11.50	6.89	9.90	4.58	1.06	1.90	...	.86	...	...
Total digestible nutrients. Actual analyses, average digestion coefficients, 1922	64.26	83.54	...	70.85	22.0	50.29	49.7	...	...	...
Total digestible nutrients. Actual analyses, average digestion coefficients, 1923—24	60.61	82.86	69.25	70.33	21.8	47.75	...	60.37	...	...
Digestible true protein, Armsby's tables	10.8	7.0	8.7	0.7	0.6	2.2	5.3	...	28.5	38.1
Net energy value, therms, Armsby's tables	53.0	85.5	67.6	75.9	15.9	43.0	39.1	55.4	88.9	99.7

*The detailed analyses of most of these feeds and the average digestion coefficients used have been given in our other publications, see Literature Cited.

TABLE 4.—Comparison of Calculated and Observed Digestibilities, Metabolism Experiments, percent

	Cow no.	Date	Dry matter	Crude protein	Ether extract	Crude fiber	N.-free extract
Digestibility of each nutrient calc. from av. digest. coef. of feeds in ration	154	1922	70.8	60.3	74.9	61.6	79.9
	All	1923—4	70.0	64.0	76.5	58.0	80.0
Observed digestibility	154	1922	66.6	55.9	49.3	54.1	75.3
	All	1923—4	63.0	52.7	36.0	46.1	72.9
Observed digest. when calc.=100%	154	1922	94.0	93.0	66.0	88.0	94.0
	All	1923—4	90.0	82.0	47.0	80.0	91.0

TABLE 5.—Production of the Four Cows Used in Metabolism Test

Production and composition	154	154	146	163	203
	5th lact. 363 days	6th lact. 366 days	6th lact. 268 days	6-months 183 days	Met. expt. only
Milk, pounds	9,646	11,793	8,490	5,281	....
Fat, pounds	342.0	364.6	284.5	203.6	....
Fat, average percent	3.55	3.09	3.35	3.85	....
Corresponding protein,* percent	3.23	2.94	3.08	3.41	....
Total protein, pounds	312	346	261	180	....
Metabolism experiment only					
Milk, daily average, pounds	32.90	29.05	30.00	31.96	29.78
Fat, daily average, pounds	.963	.872	.975	1.20	.938
Fat, average percent	2.93	3.00	3.25	3.75	3.15
Protein, average percent	2.76	3.24	3.28	3.29	3.43
Production protein, av. daily lb.	.908	.941	.982	1.05	1.02

*Calculated from a study published by the writer (30).

TABLE 6.—Nutrients Supplied Computed in Various Ways

		Cow 154 1922 period 5	Cow 154 1923—4 period 6	Cow 146 1923—4 period 6	Cow 163 1923—4 6 months	Cow 203 1923—4
Total digestible nutrients:						
1 Av. analyses and digest. coef.	(a)*	20.30	22.47	22.47	22.47	21.91
	(b)	6,567	7,819	5,886	4,031	....
2 Actual analyses and av. digest. coef.	(a)	20.32	22.32	22.32	22.32	21.76
	(b)	7,011	7,987.	5,884	4,019	....
3 Actual analyses and observed digest.	(a)	18.60	19.47	19.47	19.47	18.98
	(b)	6,382	6,898	5,074.6	3,477	....
Digestible crude protein:						
4 Average analyses and digestion coef.	(a)	1.86	1.99	1.99	1.99	1.94
	(b)	602	691	523.9	355.8	....
5 Actual analyses† and av. digest. coef.	(a)	1.72	1.79	1.79	1.79	1.75
	(b)	560	659	494	323	....
6 Actual analyses† and obs. digest.	(a)	1.59	1.49	1.49	1.49	1.45
	(b)	519.6	540.0	405.0	265.6	....
Net energy therms, Armsby average	(a)	20.45	21.43	21.43	21.43	20.89
	(b)	6,384	7,703.9	5,837.2	3,998	....
Digestible true protein	(a)	1.182	1.389	1.389	1.389	1.354
	(b)	405.5	492.7	366.1	247.9	....

*(a) Daily average—Metabolism Experiment.
(b) For entire period as stated.
†Except as noted for timothy hay on page 373.

TABLE 7.—Food Requirement and Supply—Haecker Standard

Cow	Period	Live weight used	Maintenance requirement		Production		Production requirement		Total requirement		Supplied		Excess or Deficit + —	
			D. C. P.*	T. D. N.*	Milk	Fat	D. C. P.	T. D. N.	D. C. P.	T. D. N.	D. C. P.	T. D. N.	D. C. P.	T. D. N.
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Pct.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*		
154	1 day, M. E.* 1922	1,135	0.79	9.02	32.8	2.90	1.52	9.10	2.31	18.12	1.86	20.30	—0.45	+2.18
154	1923—24	1,300	0.91	10.34	29.1	3.00	1.37	8.27	2.28	18.61	1.99	22.47	—0.29	+3.86
146	1923—24	1,200	0.84	9.54	30.0	3.25	1.44	8.92	2.28	18.46	1.99	22.47	—0.29	+4.01
163	1923—24	1,300	0.91	10.34	32.0	3.75	1.65	10.47	2.56	20.81	1.99	22.47	—0.57	+1.66
203	1923—24	1,130	0.79	8.98	29.8	3.15	1.42	8.71	2.21	17.69	1.94	21.91	—0.27	+4.22
154	363 days	1,300	330	3,753	9,646	3.55	478	3,044	808	6,797	604	6,654	—204	—143
154	366 days	1,300	333	3,784	11,793	3.09	559	3,415	892	7,163	691	7,819	—201	+802
146	268 days	1,300	244	2,771	8,490	3.35	412	2,578	656	5,349	524	5,886	—132	+641
163	183 days	1,300	167	1,892	5,281	3.85	277	1,764	444	3,656	356	4,031	—88	+447

* M. E., Metabolism experiment.
D. C. P., Digestible crude protein.
T. D. N., Total digestible nutrients equal digestible carbohydrate plus digestible protein plus 2¼ x digestible fat.

TABLE 8.—Food Requirement and Food Supply—Armsby Standard

Cow	Period	Live weight	Maintenance requirement		Production		Production requirement		Total requirement		Supplied			Excess or deficit + —	
			True protein	Therms	Milk	Test	True protein	Therms	True protein	Therms	True protein	Amids	Net energy therms	True protein	Therms
		Lb.	*Lb.*	*Lb.*	*Lb.*	*Pct.*	*Lb.*	*Lb.*	*Lb.*	*Lb.*					
154	1922, M. E.*	1,135	.567	6.50	32.8	2.90	1.39	6.86	1.96	13.36	1.18	.54	20.45	—0.78	+7.09
154	1923—24, M. E.	1,300	.650	7.15	29.1	3.00	1.25	6.10	1.90	13.25	1.35	.58	21.82	—0.55	+8.57
146	1923—24, M. E.	1,200	.600	6.77	30.0	3.25	1.32	6.75	1.92	13.52	1.35	.58	21.82	—0.57	+8.30
163	1923—24, M. E.	1,300	.650	7.15	32.0	3.75	1.50	8.15	2.15	15.30	1.35	.58	21.82	—0.80	+6.52
203	1923—24, M. E.	1,130	.565	6.77	29.8	3.15	1.30	6.55	1.87	13.32	1.31	.57	21.27	—0.56	+7.95
154	363 days	1,300	236	2,595	9,646	3.55	439	2,325	675	4,920	406	198	6,384	—269	+1.464
154	366 days	1,300	238	2,617	11,793	3.09	513	2,583	751	5,200	493	198	7,704	—258	+2.504
146	268 days	1,300	174	1,916	8,490	3.35	378	1,953	552	3,869	366	157	5,837	—186	+1.968
163	183 days	1,300	119	1,308	5,281	3.85	253	1,347	372	2,655	248	108	3,998	—124	+1.343

*Metabolism experiment.

TABLE 9.—Comparison of Data Showing Supply and Production of Protein, pounds

Cow number☞ Period☞	154 1922	154 1923—24	146 1923—24	163 1923—24	203 1923—24	154 1922	154 1923—24	146 1923—24	163 1923—24
Terms of comparison	Daily average for metabolism experiment					Total for entire period			
Digetsible crude protein supplied:									
1 Average analyses and digestibility	1.86	1.99	1.99	1.99	1.94	603	691	524	356
2 Our analyses average digestibility	1.72	1.79	1.79	1.79	1.75	560	659	494	323
3 Our analyses observed digestibility	1.59	1.49	1.49	1.49	1.45	520	540	405	265
4 Protein produced in milk	.908	.941	.983	1.051	1.021	312	346	261	180
Available for all other uses assuming 100 percent transformation feed protein to milk protein									
5 Values of line 1	.95	1.05	1.01	.94	.92	291	345	263	176
6 Values of line 2	.81	.85	.81	.74	.73	248	313	233	143
7 Values of line 3	.68	.55	.51	.44	.43	208	194	144	85
8 Maintenance requirement, Haecker standard	.79	.91	.84	.91	.79	330	333	244	167
Protein in feed above Haecker maintenance requirement for each pound of protein in milk									
9 Average figures	1.178*	1.148	1.170	1.028	1.127	.871*	1 034	1.072	1.050
10 Average digestibility, our analyses	1.024	.936	.966	.838	.941	.737	.942	.958	.866

*The apparent discrepancy in these figures is due mostly to a difference of more than 200 pounds in live weight used as the basis of the maintenance requirement.

TABLE 10.—Supply of True Protein and Protein Production

Cow number☞ Period☞	154 1922	154 1923—24	146 1923—24	163 1923—24	203 1923—24	154 1922 363 days	154 1923—24 366 days	146 1923—24 268 days	163 1923—24 183 days
Terms of comparison	Daily average for metabolism experiment					Entire period as stated			
Digestible true protein supplied: Pounds									
1 Armsby average figures	1.18	1.35	1.35	1.35	1.31	406	493	366	248
2 Our analyses average digestion coefficient*	1.09	1.25	1.25	1.25	1.22	376	470	346	225
3 Observed digestibility†	1.01	1.03	1.03	1.03	1.00	350	385	284	185
4 Protein produced in milk	.908	.941	.983	1.05	1.02	312	346	261	180
Available for all other uses, assuming 100 percent transformation feed protein to milk protein—pounds									
5 Values of line 1	.27	.41	.37	.30	.29	94	147	105	68
6 Values of line 2	.18	.31	.27	.20	.20	64	124	85	45
7 Values of line 3	.10	.09	.05	—.02	—.02	38	39	23	5
8 For maintenance alone, Armsby standard	.57	.65	.60	.65	.57	236	238	174	119
Digestible true protein in feed for each pound produced in milk above Armsby maintenance requirement—pounds									
9 Average figures	.671	.744	.763	.666	.725	.545	.737	.735	.717
10 Our analyses average digestion coefficients	.573	.637	.661	.571	.637	.448	.670	.659	.588

*Armsby's ratio between crude and true protein, our analyses average digestion coefficient.
†As line 2 except observed digestibility.

TABLE 11.—Calculated from Tables E and F opposite page 64, Bul. 225, Vermont Agr. Exp. Station, 1922

Lactation	From Table E, entire year in addition to pasture					From Table F, winter period 7 months				
	Average live weight	Supplied in food daily		Protein in milk	Balance for maintenance etc.	Average live weight	Supplied in food daily		Protein in milk	Balance for maintenance etc.
		Protein	T. D. N.				Protein	T. D. N.		
*	Very low protein feeding									
L. A.† 6	873	0.79	8.65	0.60	0.19	840	1.20	13.16	0.69	0.51
L. A. 4	803	.69	8.25	.52	.17	833	1.08	12.71	.77	.31
L. A. 6	873	.78	8.60	.61	.17	840	1.21	13.22	.71	.50
L. A. 4	803	.71	8.23	.50	.21	833	1.08	12.74	.74	.34
L. C.‡ 13	861	.80	9.33	.55	.25	867	1.08	12.55	.61	.47
L. C. 10	786	.69	8.16	.47	.22	806	0.95	11.47	.45	.50
L. C. 13	861	.82	9.38	.56	.26	867	1.08	12.66	.63	.45
L. C. 10	786	.69	8.10	.47	.22	806	0.93	11.35	.45	.48
Average...	831	...	...	...	0.21	836	...	...	...	.445
	Low protein feeding, same tables									
L. A. 8	823	0.92	8.51	.57	.35	830	1.54	11.70	.70	.84
L. A. 3	877	1.09	9.57	.67	.42	862	1.36	12.38	.76	.60
L. A. 8	823	.89	8.30	.57	.32	830	1.50	11.68	.69	.81
L. A. 3	877	1.03	9.06	.56	.47	862	1.35	12.26	.69	.66
L. C. 5	920	1.06	9.54	.50	.56	914	1.34	11.81	.54	.80

*The figures in this column indicate either the number of cows or the number of lactation periods included in the study.
†L. A., The cows in this group were alternated by lactation periods from a high to a low protein ration.
‡L. C., The cows in this group were restricted to the designated ration continuously for several successive lactations.

TABLE 12.—Supply of Digestible Crude Protein and of Total Digestible Nutrients Consumed and of Milk and Fat Produced During Four Successive Lactation Periods

Lactation		Production						Digestible nutrients supplied				Nutritive ratio
Number	Length days	Total		Average daily		Calculated for 366 days		Crude protein	Total	Calculated for 366 days		
		Milk	Fat	Milk	Fat	Milk	Fat			Crude protein	Total	
Cow 146												
3	335	9,698	376.1	28.95	1.12	10,596	409.9	1,127	5,979	1,230	6,533	1:4
4	365	10,704	441.1	29.32	1.21	10,733	444.2	1,255	6,341	1,259	6,358	1:4
5	320	10,064	406.3	31.45	1.27	11,511	464.8	762	6,478	871	7,978	1:9
6	268	8,490	284.5	31.68	1.06	11,602	388.0	524	5,886	717	8,037	1:11
Cow 154												
3	317	8,530	298.8	26.9	.942	9,845	344.7	613	5,994	706	6,917	1:9
4	341	9,720	332.4	28.5	.975	10,431	356.9	714	6,752	765	7,247	1:9
5	363	9,646	342.0	26.6	.935	9,735	342.2	603	6,567	607	6,570	1:11
6	366	11,793	364.6	32.2	.996	11,793	364.6	691	7,819	691	7,819	1:11

TABLE 13.—Effect of Protein on Economy of Production

Cow	Lactation	Production, 365-day basis				Digestible nutrients supplied		4 percent milk per lb. D. N.
		Milk	Fat	Fat	Equivalent 4 percent milk	Crude protein	Total	
No.	No.	Lb.	Lb.	Pct.	Lb.	Lb.	Lb.	Lb.
Ratio 1:11, or approximately 8⅓ percent protein content								
146	6	11,570	387	3.4	10,378	715	8,015	1.29
154	5	9,709	341	3.5	8,884	605	6,552	1.36
154	6	11,761	364	3.1	9,915	689	7,798	1.27
Average..		11,013	364	....	9,726	669	7,455	1.31
Ratio 1:2, or approximately 33⅓ percent protein content								
192	3	9,355	359	3.8	9,074	2,217	6,508	1.39
Ratio 1:9, or approximately 10 percent protein content								
59	4	8,392	252	3.0	6,931	570	5,885	1.18
	5	7,769	231	2.95	6,371	634	6,124	1.04
	6	7,643	238	3.0	6,313	562	5,400	1.21
61	3	6,151	342	5.5	7,547	547	5,468	1.38
	5	5,663	320	5.7	7,067	579	5,574	1.27
111	1	7,631	254	3.3	6,707	514	5,290	1.27
	2	9,201	292	3.7	7,913	719	6,801	1.17
	3	10,306	328	3.2	8,863	687	6,388	1.39
	4	10,913	347	3.2	9,385	715	6,698	1.40
	5	10,061	326	3.2	8,652	770	7,269	1.19
	6	9,964	326	3.3	8,758	772	7,375	1.19
154	1	7,117	270	3 8	6,903	639	5,874	1.19
	2	9,275	321	3.5	8,487	619	5,792	1.47
	3	9,845	345	3.5	7,532	611	5,978	1.26
	4	10,431	357	3.4	9,356	712	6,734	1.39
146..	5	11,480	464	4.0	11,480	869	7,956	1.44
Average....		8,865	307	. .	8,016	658	6,288	1.27

TABLE 13.—Effect of Protein on Economy of Production—Concluded

Cow	Lactation	Production, 365-day basis				Digestible nutrients supplied		4 percent milk per lb. D. N.
		Milk	Fat	Fat	Equivalent 4 percent milk	Crude protein	Total	
No.	No.	Lb.	Lb.	Pct.	Lb.	Lb.	Lb.	Lb.
Ratio 1:6.5, or approximately 15 percent protein content								
53	3	7,801	388	4.95	8,846	869	6,271	1.41
59	2	7,683	242	3.15	6,528	751	5,882	1.11
	7	6,833	215	3.15	5,815	822	5,909	.984
	8	6,862	206	3.00	5,668	849	5,875	.964
61	2	5,745	323	5.60	7,089	802	6,092	1.16
64	2	6,680	326	4.90	7,522	832	5,792	1.30
	3	6,650	330	4.95	7,541	746	5,960	1.27
	4	7,030	350	5.00	8,028	759	5,763	1.39
	5	7,209	379	5.25	8,514	716	5,453	1.56
	6	6,941	372	5.35	8,301	715	5,429	1.53
66	1	10,325	373	3.60	9,644	918	6,596	1.46
67	1	7,628	301	3.95	7,567	742	5,386	1.40
	2	8,161	337	4.10	8,259	870	6,235	1.32
	3	7,982	325	4.10	3,078	653	5,192	1.56
	4	7,709	307	4.00	7,709	732	5,473	1.41
122	1	3,551	182	5.10	4,112	544	4,053	1.01
	2	4,234	208	4.90	4,767	659	4,714	1.01
157	1	3,896	204	5.25	4,601	522	3,742	1.22
Average.....		6,829	298	....	7,144	750	5,545	1.28
Ratio 1:4, or approximately 20 percent protein content								
53	4	8,767	445	5.1	10,152	1,157	5,759	1.76
	5	6,716	326	4.9	7,562	1,175	5,937	1.27
	6	7,066	351	5.0	8,069	985	5,011	1.61
66	2	11,041	408	3.7	10,511	1,343	6,846	1.53
	4	9,634	364	3.8	9,345	1,164	6,019	1.55
	5	11,966	423	3.5	10,949	1,579	7,351	1.49
111	7	12,574	427	3.4	11,279	1,466	8,277	1.36
192	1	9,360	357	3.8	9,079	1,089	5,683	1.60
	2	10,229	383	3.7	9,738	1,264	6,341	1.53
146	1	9,636	362	3.8	9,347	1,280	5,982	1.56
	2	9,864	363	3.8	9,568	1,246	5,965	1.60
	3	10,567	409	3.9	10,408	1,227	6,515	1.60
	4	10,704	443	4.1	10,831	1,255	6,340	1.71
Average.....		9,856	389	....	9,757	1,248	6,309	1.55